emitted which consists of the characteristic radiation of the material, excited by the β-rays of radium C, together with the soft radiation emitted by radium C.

I wish to express my sincere thanks to Sir Ernest Rutherford for the constant help and valuable advice which he has given to me throughout these experiments.

Electrification of Water by Splashing and Spraying.

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The experiments of Lenard[*] and Sir J. J. Thomson[†] on the electrification produced by the splashing of pure water and other liquids are well known. It was found that distilled water when splashed at a metal obstacle took up a positive charge, giving a negative charge to the air. Very dilute solutions of different substances gave very remarkable results, the sign and magnitude of the charge on the liquid depending on the dissolved substance and the degree of concentration of the solution. In all cases the electrification ultimately approached zero as the strength of the solution increased, so that for solutions of quite moderate strength the effect was inappreciable. Simpson[‡] has shown that if drops of distilled water are allowed to fall into a vertical jet of air of sufficient velocity, the drops are broken up and acquire a positive charge. Investigations of the electrification produced in the air when splashing takes place have been made by Kähler,[§] Aselmann[||] and Simpson. Similar investigations have been made in connection with bubbling and spraying of liquids by Townsend,[¶] Sir J. J. Thomson,[**] Kosters[††], Eve[‡‡] and M. Bloch.[§§] A complete account of the subject will be found in a memoir by J. J. Rey.[||||]

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[*] Lenard, 'Wied. Ann.,' vol. 46, p. 584 (1892).

[†] J. J. Thomson, 'Phil. Mag.,' vol. 37, p. 341 (1894).

[‡] Simpson, 'Phil. Trans.,' vol. 209, p. 379 (1909).

[§] Kähler, 'Ann. der Phys.,' vol. 12, p. 1119 (1903).

[||] Aselmann, 'Ann. der Phys.,' vol. 19, p. 960 (1906).

[¶] Townsend, 'Camb. Phil. Soc. Proc.,' vol. 9, part 5 (1898).

[**] J. J. Thomson, 'Phil. Mag.,' p. 352 (1902).

[††] Kosters, 'Wied. Ann.,' vol. 69, p. 12 (1899).

[‡‡] Eve, 'Phil. Mag.,' vol. 14 (1907).

[§§] M. Bloch, 'Comptes Rend.,' vol. 145, p. 54 (1907).

[||||] Rey, 'Sur l'Ionisation de l'Air par les Chutes d'Eau,' Gauthier-Villars, 1912.

The work described in this paper was undertaken with a view to obtaining some precise data from which it might be possible to establish a connection between the charge produced on the liquid and the extent to which it had been broken up.

The liquid used throughout was distilled water, and two methods were employed for breaking it up in contact with air. These were (1) by splashing against an air-blast and (2) by spraying. The experiments made by these methods are described in detail.

First Method: Splashing Distilled Water against an Air-Blast.

This method resembles that employed by Simpson, but it is more effective and allows the splashed water to be more readily examined. Drops were allowed to fall into a very strong horizontal air-current. Each drop as it entered the air-stream was immediately shattered. A mixture of small drops of different sizes was produced, including a small number of drops of medium size as well as a great number of exceedingly fine drops. These drops were carried forward through different distances by the impetus given by the air-blast, the larger drops being carried farther. A rough sorting-out of the drops into different sizes was thus effected, and it would be possible, by allowing the drops to fall into a vessel set at different points, to compare the charge per cubic centimetre of water for drops of different sizes. Some experiments conducted in this manner showed at once that the charge per cubic centimetre depended on the size of the drops into which the water was broken, the charge being greater as the size of the drops decreased. This method was not, however, found suitable for making accurate measurements of the two quantities concerned. The drops falling into the receiving vessel at any point were a mixture in varying proportions of drops varying over a considerable range in size. The accidental occurrence of a few large drops would make a very great difference in the results of any measurement. These difficulties were not encountered to such an extent if the receiving vessel was set up immediately under, or only very slightly in advance of the point at which the breaking-up of the water occurs. A rain of fine drops descended from that point without any intermixture of large drops. The variation of size amongst the drops collected by the receiving vessel in this position was not very serious. Measurements could therefore be made with a fair degree of accuracy. The size of the drops falling into the receiver could be varied by varying the strength of the air-blast and by varying the height of the dropper. If the strength of the air-current is increased, or if the height from which the water falls is increased, the size of the drops falling into the receiver is diminished. But we are restricted to a certain small range, for if the air-current is increased beyond a certain point the spray will be carried forward to such an extent that the residue of fine drops falling into the receiver is insufficient for purposes of experiment. Again it was found that if the height of the dropper was increased beyond a certain point the breaking-up of the drops occurred in such a way as to cause an admixture of large sized drops amongst the fine spray falling into the collecting vessel. In spite of these limitations it was found possible to produce a considerable variation in the size of the rain-like spray which fell from the point at which the breaking-up of the water drops occurred. In some cases the receiving vessel was moved forward so as to capture the larger sized drops which had been carried forward some distance by the air-blast. A few successful observations were made in this way, but the risk of error due to the occurrence of large drops is much increased.

The arrangement of apparatus shown in the diagram (fig. 1) was adopted.

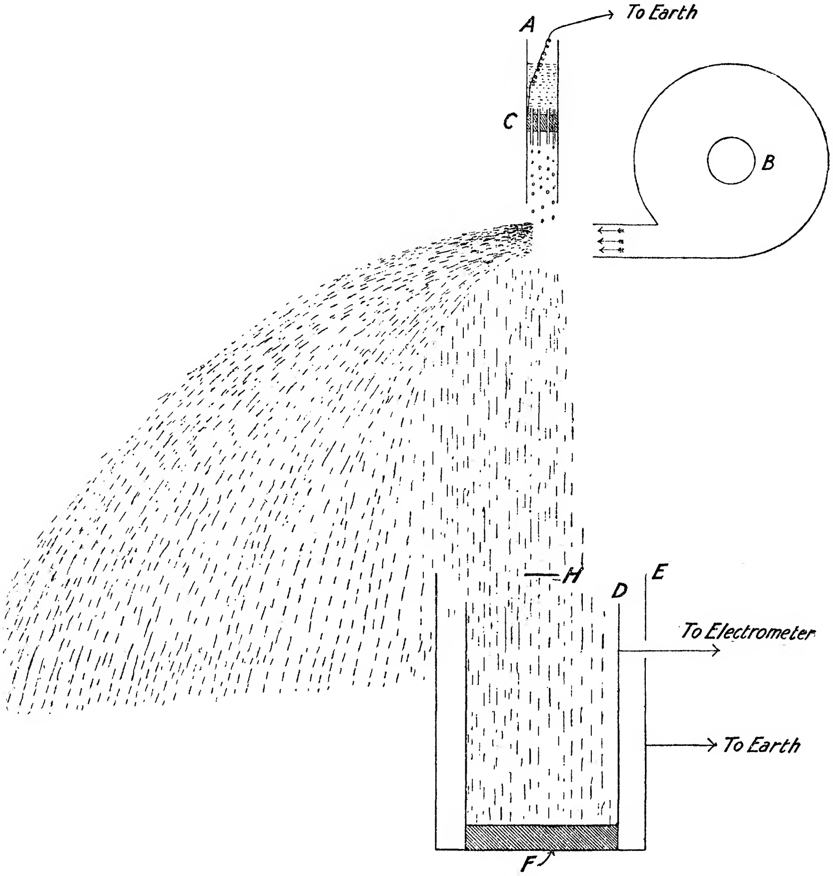

FIG. 1.

B is a Sirocco fan driven by a motor and giving a very strong horizontal blast of air. A is the water-dropping arrangement. It is of glass with a cork at C pierced by 18 short pieces of narrow-bore glass tubing. The upper part is filled with distilled water, and the whole connected to earth. A rapid succession of drops is thus obtained. The radius of the drops was approximately 0·25 cm. The receiving vessel D is of cylindrical form, 30 cm. in diameter, insulated on paraffin (F) and connected to a Dolezalek electrometer. It is surrounded by a larger vessel E connected to earth.

It is easy to show that the drops coming away from the dropper are uncharged (as far as concerns quantities dealt with in these experiments). When the fan is not acting and the drops consequently fall directly into the receiver, no appreciable charging occurs. Furthermore in this case we are collecting about five hundred times more water per second than when the fan is acting. When splashing occurs the receiver charges up strongly, and the charge carried by the drops can be measured very accurately. It is more difficult to estimate the quantity of water entering the receiver in any given time and to get a measurement of the size of the drops. The amount of water was determined by finding the increase in weight of a piece of blotting paper cut to fit the bottom of the receiving vessel. There is an error introduced here owing to the evaporation from the blotting paper, but it was found that if the second weighing was completed rapidly, the error was not very serious.

We have thus obtained the total weight of water and the amount of charge which it carried. The next step is to obtain the total number of drops which have fallen into the receiver. This would enable us to find the size of each drop. Two points must be considered at this stage, (1) the number of drops falling into the receiver per second may vary throughout the experiment, and (2) the number of drops falling per unit area into different parts of the receiver may be different. Before adopting any counting method these points must be examined. A ruled surface exposed to the drops for a certain small time at different stages of the experiment showed that if any error due to the first cause was present, it was masked by the ordinary irregularities to which the experiment is subject. The same remark applies to observations on the second point. These irregularities, however, were not so great as to prevent the counting experiments being made with a fair degree of accuracy. Two observations were always made, one at the beginning and one at the end of each experiment, of the number of drops falling per square centimetre per second into the centre of the receiver. Generally, these observations agreed fairly well. In any case in which there was a considerable discrepancy the observation was rejected.

The method of procedure adopted in most of the experiments was as follows: The weighed paper was placed in the vessel D and the fan was started. The dropper was filled with distilled water, and the charging-up of the receiver was observed until the dropper was empty. The time during which the water-dropper was acting was noted by means of a stop-watch. It was generally about $2\frac{1}{2}$ minutes. The final reading of the electrometer was noted and the paper in D removed and rapidly weighed. At the beginning and again at the end of the experiment a sheet of metal, 4 cm. square, ruled in centimetre squares was introduced at H and exposed for 10 seconds. Owing to the relatively small area of this piece of metal and the shortness of the time for which it was exposed, its introduction did not appreciably affect the amount of water captured by the receiver. It was also easy to verify that its introduction did not affect the rate of charging of the electrometer. The number of drops which had fallen on each square was quickly counted and noted. From the two observations a mean value was obtained from which it was possible to calculate the total number of drops which entered the receiver during the time of the experiment. Hence the mean volume of the drops could be found.

The observations taken in one experiment are quoted here so as to give an indication of the magnitudes involved:—

Duration of experiment....................	$2\frac{1}{4}$ minutes.
Electrometer deflection	143 divisions positive.
Capacity of electrometer and vessel......	292 cm.
Sensibility of electrometer	846 divisions per volt.

$$\text{Positive charge received} = \frac{143 \times 292}{300 \times 846} \text{ E.S.U.}$$

$$= 0{\cdot}164 \text{ E.S.U.}$$

Weight of paper (1)	8·743 grm.
„ „ (2)	9·015 „

$$\text{Weight of water collected} = 0{\cdot}272 \text{ grm.}$$

$$\text{Charge per cubic centimetre of water} = \frac{0{\cdot}164}{0{\cdot}272} \text{ E.S.U.}$$

$$= 0{\cdot}60 \text{ E.S.U.}$$

Mean number of drops per square centimetre in 10 seconds ...	3
Area of receiving vessel	660 sq. cm.

$$\text{Volume of each drop} = \frac{0{\cdot}272}{3 \times 2\frac{1}{4} \times 6 \times 660} \text{ c.c.}$$

$$= 102 \times 10^{-7} \text{ c.c.}$$

Hence the charge per cubic centimetre corresponding to drops of volume 102×10^{-7} c.c. is 0·60 E.S.U.

When suitable conditions were arrived at as regards strength of the air-blast, etc., the drops were generally fairly uniform in size, as could be verified by examining those captured on the ruled metal surface. One or two large drops, however, accidentally entering the receiving vessel would vitiate any measurement. In many cases this source of error was easily detected on account of the unmistakable marks which the large drops left on the blotting-paper. But there is no doubt that it is impossible to be altogether immune from errors of this kind. Great difficulty was experienced in obtaining concordant readings of the size of the drops. It was hoped that if a great number of experiments were performed, it would be possible to approach a correct result.

A great number of the experiments were rejected for various reasons. The results which were retained and which are believed to be reliable are set forth in the following Table. Many of the numbers given below represent the means of two or more observations, as drops of certain sizes (or very closely approximating to those sizes) tended to recur throughout the experiments:—

Table I.—Positive Charge per Cubic Centimetre on Distilled Water broken into Drops of different Sizes.

Charge per cubic centimetre in electrostatic units.	Volume of drops.	Radius of drops.
	c.c.	cm.
0·54	106×10^{-7}	$13·7 \times 10^{-3}$
0·60	102	13·5
0·68	100	13·4
0·79	84·7	12·7
0·80	46	10·3
0·86	50·5	10·6
0·92	20	7·8
0·95	32	9·1
1·01	18·3	7·5
1·34	8·5	5·9
1·36	8·6	5·9

An examination of this Table shows that, in spite of certain irregularities, there is a steady increase in the value of the charge per cubic centimetre as the size of the drops gets smaller. This is illustrated by plotting the values of the charge per cubic centimetre against the reciprocal of the radius of the drops. In the graph (fig. 2), the points obtained from the foregoing Table are shown by the small circles. (The points marked by crosses will be dealt with later.) The points lie roughly about a straight line passing through the origin. This gives us the very simple relation $E = K/r$, where E is the charge per cubic centimetre, r the radius of the drops, and K a constant.

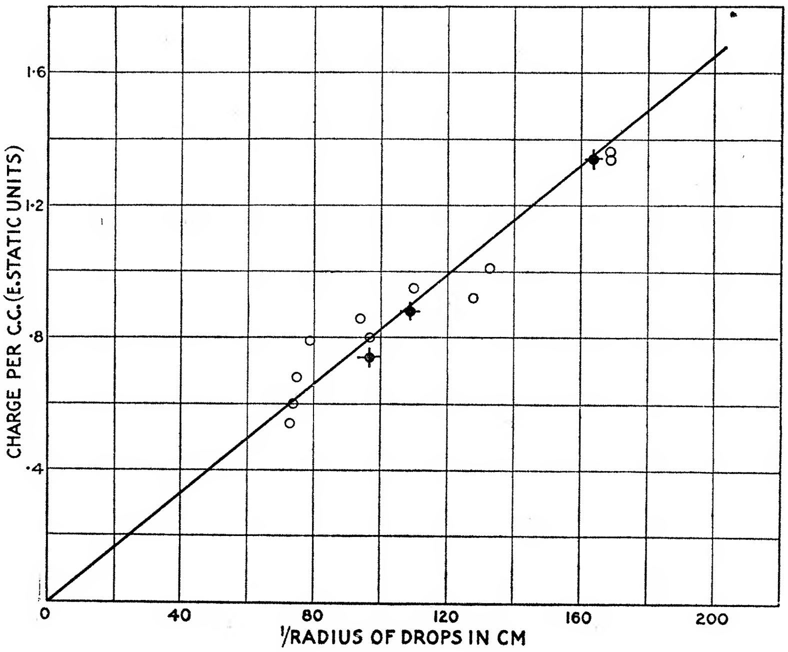

Fig. 2.

This result is readily interpreted if we make a simple assumption as to the manner in which the water becomes charged. Let us suppose that the charge on the water is proportional to the area of the new water surface created. When a drop of radius R is broken into a great number (n) of small drops of radius r, the increase in surface is

$$4\pi r^2 n - 4\pi R^2.$$

Let σ be the charge on the water per unit area of new surface. Then the total charge is

$$4\pi\sigma(r^2 n - R^2)$$

$$\therefore \quad E \text{ (charge per cubic centimetre)} = \frac{4\pi\sigma(r^2 n - R^2)}{\frac{4}{3}\pi r^3 n}$$

$$= 3\sigma\left(\frac{1}{r} - \frac{R^2}{r^3 n}\right)$$

$$= 3\sigma\left(\frac{1}{r} - \frac{1}{R}\right).$$

In the experiments described above, R is large compared with r, therefore we may write

$$E = \frac{3\sigma}{r},$$

giving the relation between E and r which has been found experimentally.

From the numbers already given we can calculate the value of the constant σ. The following Table gives the value of σ calculated for each observation :—

Table II.

E in electrostatic units.	σ in electrostatic units.
0·54	$2{\cdot}46 \times 10^{-3}$
0·60	2·70
0·68	3·04
0·79	3·34
0·80	2·74
0·86	3·04
0·92	2·39
0·95	2·88
1·01	2·52
1·34	2·63
1·36	2·67
Mean value of σ	$2{\cdot}76 \times 10^{-3}$

It will be noticed that there is a considerable variation in the values of σ, the highest being $3{\cdot}34 \times 10^{-3}$ E.S.U., and the lowest $2{\cdot}39 \times 10^{-3}$ E.S.U. But the agreement is quite as good as could be expected considering the difficulties of the experiment. It is possible that by some constantly occurring experimental error, the mean value of the constant σ, as determined by these experiments, is erroneous. But there can hardly be any doubt as to the general law expressing the electrical separation that occurs when water is splashed. This may be stated

$$Q = \sigma\, dA,$$

Q being the charge, positive on the water, and dA the increase in area of the water-surface.

Second Method: Spraying Distilled Water.

In order to test the generality of the result obtained above, another set of experiments was undertaken, using a different method of breaking up the water. Different forms of spraying apparatus were tested, and after some trials an ordinary scent spray was adopted. When driven by air under pressure, this spray gave a copious supply of water in fine drops. The size of the drops could be varied by varying the air pressure. Owing to the large quantities of water given by the sprayer the determination of the charge per unit volume was extremely easy. So great were the electrical quantities involved that in some cases it was necessary to increase the capacity of the electrometer system by 0·2 microfarad. Spurious effects, however, of two kinds have to be guarded against. In the first place, the sprayer has to be well screened against any electrostatic field, otherwise the "water-dropper" effect will occur at the nozzle and the sprayed water will carry away a charge depending in sign and magnitude on the direction and strength of the field. In the second place it is possible that the water may become charged by friction against the nozzle. Any effect at the nozzle other than the true air-water effect which we are investigating would give the water a charge of one sign and leave the nozzle with an equal charge of the opposite sign. Consequently if the rate of charging of the nozzle be observed, the charge on the water due to effects of this kind may be allowed for.

The arrangement of the apparatus is shown in Fig. 3. The sprayer taken from an ordinary scent-spray is fitted to a vessel containing distilled water. The nozzle, which is of brass, is set so that the spray is directed downwards.

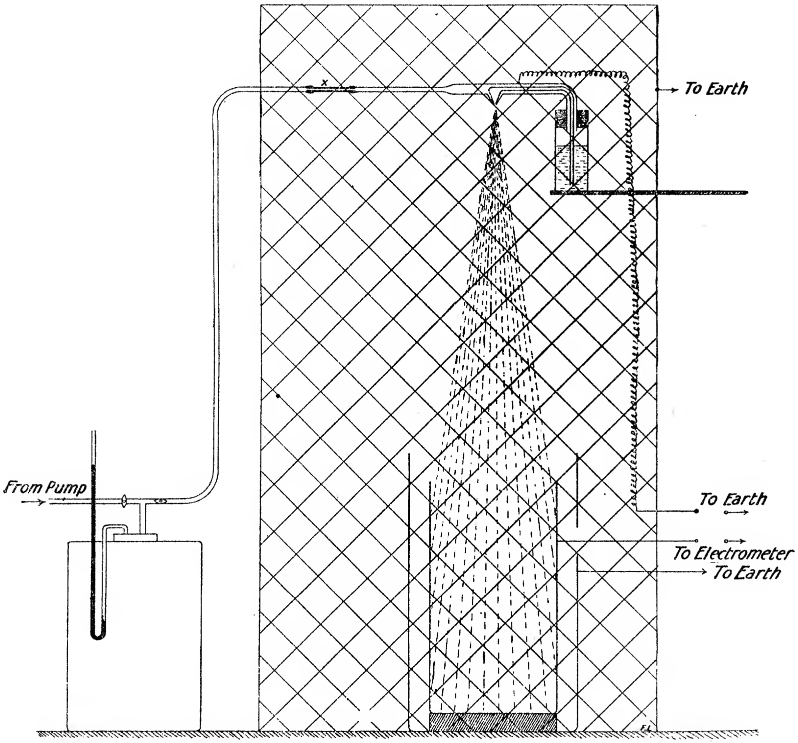

Fig. 3.

The size of the sprayer is much exaggerated in the drawing, the orifice being in reality a mere pin-hole. The sprayer is connected by rubber tubing with the air-supply contained in a reservoir. The pressure in the reservoir is read off by means of a mercury manometer and it can be maintained at any desired value by means of a hand-pump. A length of ebonite tubing is introduced at X. As the sprayer is insulated from its support, it is thus possible to insulate the spraying system. All the sprayed drops are caught in the receiver, which is set up in the same fashion as in the previous experiments. An arrangement is introduced by which the receiver and the sprayer can be connected either to earth or to the electrometer. The apparatus is enclosed in a cage of wire netting connected to earth. This excludes the possibility of disturbing electrostatic influences.

The method of working is as follows:—The pressure is brought to the required value and is kept constant throughout the experiment, usually a few strokes of the hand-pump are sufficient. The sprayer is connected to earth and the charge gained by the receiver per minute observed. Then the receiver is earthed and the charging of the sprayer observed. The algebraic sum of the charges gives that part of the charge on the water due to the true air-water effect. The water sprayed per minute is easily measured and the charge per unit volume is at once obtained.

The results given below are, in all cases, the means of several experiments.

Table III.—Charge per Cubic Centimetre on Water sprayed at different Pressures.

Pressure.	Charge per minute on receiver.	Charge per minute on sprayer.	Corrected charge per minute on water.	Volume of water sprayed per minute.	Charge per cubic centimetre (E).
cm. Hg.	E.S.U.	E.S.U.	E.S.U.	c.c.	E.S.U.
7·6	+12·4	+4·6	+17·0	23	0·74
11·6	+29·0	−0·6	+28·4	32	0·88
19·6	+62·7	−8·9	+53·8	40	1·34

It will be observed that the charge contributed to the water by the sprayer changes sign as the pressure is increased. No detailed investigation of this point was made.

Another set of experiments was now necessary in order to estimate the size of the drops corresponding to different values of E. The method employed in the previous experiments was adopted, but modifications were necessary owing to the very great number of drops that had to be dealt with. The sprayer was set up in a closed space so that the spray was not disturbed by draughts. The spray fell upon a shutter which could be opened and closed very quickly, exposing a small sheet of silver ruled in square millimetres. The shutter was connected electrically with a chronograph reading to 1/1000 sec., so that the time for which the shutter was open was known very accurately. It was generally of the order of 1 second. After an exposure, the sheet of silver was withdrawn and quickly covered with a watch-glass to prevent evaporation. The number of drops per square millimetre was counted, a low-power microscope being sometimes used for this purpose. These measurements gave the number of drops falling per square centimetre per second. It was only necessary to set up in the same position a small vessel and weigh the water which it captured in a known time, in order to have sufficient data to calculate the average volume per drop.

Considerable difficulties were experienced in making these measurements. At first, the number of drops counted per second varied in an irregular manner. Afterwards, when various devices were adopted to secure steadiness, this variation was reduced somewhat, but it was difficult to entirely eliminate it. A great number of experiments were made and the mean of the results taken. It is believed that the result is fairly correct; certainly experiments made at different times agree amongst themselves.

Results calculated from the best observations are given below.

Table IV.—Volume and Charge of Sprayed Drops.

Pressure.	Volume of drops.	Radius of drops.	E.	σ.
cm. Hg.	c.c.	cm.	E.S.U.	E.S.U.
7·6	$46 \cdot 2 \times 10^{-7}$	$10 \cdot 3 \times 10^{-3}$	0·74	$2 \cdot 54 \times 10^{-3}$
11·6	32·5	9·2	0·88	2·70
19·6	9·5	6·1	1·34	2·72

In the last column are given the values of σ calculated as before from the formula $\sigma = Er/3$. This formula will hold as in the first experiments, because here again the original water-surface may be neglected in comparison with the final area, so that we have

$$E = \frac{3\sigma}{r},$$

as before.

The agreement with the values of σ obtained by the splashing method is very striking. The agreement is shown on fig. 2, where the values of E and $1/r$ by the spraying method are marked by crosses. So good an agreement between the results of the two methods was, indeed, scarcely to be expected.

In addition to the sources of error in both experiments which have already been referred to, there is a very great difference in the two methods as regards the air which carries the corresponding negative charge. In the first method the negative charge is carried away in the current of air from the fan, and the drops of water on which the charge is measured fall directly out of the air-current. In the second method the positively charged water and the negatively charged air are blown in the same direction by the sprayer. However, the identity of the constant σ determined by these two methods of experiment can hardly be doubted.

Since the value of σ is comparatively high, it should be possible to measure the charge due to small changes in a water-surface. A number of experiments were attempted with this object. Water was allowed to ascend into a funnel-shaped vessel so that the area of the water-surface was rapidly increasing. No charge could be detected on the water. A strong current of air was blown over the water-surface while it was changing in area, so as to carry off the negative ions if any were produced. No difference could be detected. If a jet of air is set so as to play on a water-surface ripples are produced, but no charging can be detected until the strength and direction of the air-blast are such that the water-surface is broken and drops are carried off in the blast. The water-surface then takes on a strong positive charge. These experiments indicate that some sort of violent and disruptive action is necessary in order to produce the charge on a water-surface. It would seem as if it were necessary to produce a virgin liquid surface, and that merely to expand an old surface is ineffective. An account of some experiments somewhat similar to those just described was afterwards found in the memoir of J. J. Rey already referred to. Here, again, it is found that none of the ordinary methods of changing a water-surface will produce an electrical separation.

Experiments on Different Liquids.

All the experiments described up to this point were made with distilled water. This was the ordinary distilled water of the laboratory, in the preparation and storage of which no specially high degree of purity is aimed at. Ordinary tap-water and some solutions were also examined by the methods of splashing and spraying. No systematic investigation of either was attempted. The results obtained harmonise with those of Lenard, Sir J. J. Thomson, and other workers. The Dublin tap-water gives an effect 1/8 or 1/10 that of distilled water Strong solutions give no charge, weak solutions giving positive or negative values, depending on the solute and the concentration.

Experiments on the Electrification of the Air from the Sprayer.

The air drawn from the sprayer was examined in order to find how the negative charge was carried. It is hoped to give a detailed account of these experiments later, when the results are more complete. A *résumé* may be given here, however. The air was found to contain large numbers of ions of both signs, with, of course, an excess of negative. There appears to be present a number of different classes of ions, each class having a definite mobility. The values of the mobility vary from that of the ordinary atmospheric ion to that of the large ion discovered by Langevin,* and investigated by Pollock† and McClelland and Kennedy.‡ Thus the largest ion present has a value for the mobility in a field of 1 volt per centimetre of 0·00035 cm. per second approximately. This is true for both positive and negative. The ion coming next in order of size has a mobility about three times this value. There appears to be no intermediate class. Again, at the other end of the scale we find ions of both signs with a mobility of about 1·5 cm. per second, apparently identical with the ordinary atmospheric ions. There are also present negative ions of mobility 3 cm. per second, but no indications of positive ions of that mobility. Between the small and the large ions there are groups of ions of various mobilities which have not been fully investigated. It is probable that the excess of negative charge on the air is present mainly as small ions, as it is in the number of small ions that the negative charge predominates most markedly.

Conclusion.

The simple connection demonstrated in this paper between the electrification due to spraying and splashing and the change in area of the liquid surface concerned should help to throw some light on the origin of the electrification in these cases. A further investigation of similar effects, and especially a detailed investigation of the nature of the electrification of the air in the different cases, must be completed before an attempt is made to put forward a theory of the effect.

In conclusion, the writer wishes to express his indebtedness to Prof. McClelland, who suggested this research, for his continued help and interest during its progress.

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* Langevin, 'Comptes Rend.,' vol. 140, p. 232 (1905).

† Pollock, 'Le Radium,' vol. 6, p. 129 (1909).

‡ McClelland and Kennedy, 'Roy. Irish Acad. Proc.,' vol. 30, sec. A, p. 72 (1912), and Kennedy, 'Roy. Irish Acad. Proc.,' vol. 32, sec. A, p. 1 (1913).